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Perspectives on biodiesel as a sustainable fuel

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ABSTRACT

The present global economy downturn affects every corner of the world including the vehicular fuel industry. This paper highlights some of the perspectives for the biodiesel industry to thrive as an alternative fuel, while discussing benefits and limitations of biodiesel. This includes the improvement of the conversion technology to achieve a sustainable process at cheaper cost, environmentally benign and cleaner emissions, diversification of products derived from glycerol, and policy and government incentives. More specifically, an overview is given on making the production process more economical by developing high conversion and low cost catalysts from renewable sources, and utilizing waste oil as feedstock. Further emphasis is given on the need for public education and awareness for the use and benefits of biodiesel, while promoting policies that will not only endorse the industry, but also promote effective land management.

Contents

1. Introduction

Biodiesel (fatty acid alkyl esters) is an alternative diesel fuel derived from the reaction of vegetable oils or lipids and alcohol with or without the presence of a catalyst. Despite the invention of the vegetable oil fuelled engine by Rudolf Diesel dated back in the 1900s, full exploration of vegetable oil based fuel such as biodiesel only came into light in the 1980s as a result of renewed interest in renewable energy sources for reducing greenhouse gas (GHG) emissions, and alleviating the depletion of fossil fuel reserves [1]. Since then, biodiesel has slowly penetrated the market in Europe, especially in Germany and France, as a blend to petro diesel. Commercially, these blends are named as B5, B20 or B100 to represent the volume percentage of biodiesel component in the blend with petro diesel as 5, 20 and 100 vol.%, respectively. Currently, many countries around the world have explored and

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commercially used biodiesel blends for their vehicles such as US, Japan, Brazil, India, and so on.

Esterification and transesterification reactions are currently the most favoured reaction pathways to produce biodiesel. Any type of feedstock that contains free fatty acids and/or triglycerides such as vegetable oils, waste oils, animal fats, and waste greases can be converted into biodiesel. However, the final products must meet stringent quality requirements before it can be accepted as biodiesel (EN14214 for European standard; ASTM D6751 for US). The fuel properties of B5, B20, B100 and No. 2 Diesel, according to the standards, are well established in the literature [2–6]. A number of processing technologies for the production of biodiesel have been reported as the feedstock conversion that depends on the type of feedstock used.

While the biodiesel industry is being established in many countries, it has also been hit by the current global economic crisis. In order to overcome the adversities of the economic background, it is critical for the biodiesel industry to continuously improve on aspects that will strengthen the prospects of better market penetration. There are numerous review papers recently published focusing on the specific issues related to production processes [7–9], feedstock [8,10–12], engine testing and emission [13,14], and social, economy and policy [15–17]. In this paper, we highlight the important aspects of the biodiesel which will strengthen the prospect as the next generation green fuel. Four major areas are discussed:

(i) cost and environmental impact of conversion processes;
(ii) efforts towards environmentally benign and cleaner emissions;
(iii) diversification of products derived from biodiesel glycerol;
(iv) policy and government incentives.

Some points require further advancement of research, while others may be controlled by regional policies. Nevertheless, these points are critically discussed in the following.

2. Cost and environmental impact of conversion process

For a sustainable future of the planet, we must look into renewable energy sources which implicitly include sustainable fuel sources. Based on the positive energy balance or life cycle analysis, biodiesel is shown to be sustainable [18]. However, competition of feed source with food, and destruction of natural habitats resulting from energy crop plantation are some inevitable issues which require attention. Furthermore, various aspects in increasing the economic perspectives of the biodiesel are examined.

2.1. Efficient processes

One of the benefits of biodiesel is that it can be produced from a wide range of feedstock types, ranging from controversial neat vegetable oils to environmentally polluting waste oils. However, the latter contains unfavourable components such as high particulates, free fatty acids and water content requiring a suitable pre-treatment process [19]. For neat vegetable oils, the process is relatively simple using alkaline homogeneous transesterification, with conversion efficiency of more than 98% [5]. However, the homogeneous transesterification has a disadvantage as it consumes large amount of water for wet washing to remove the salt produced from the neutralization process, and the residual acid or base catalyst. In spite of this, there are many companies commercializing this technology, such as MPOB, Lurgi, EsterFIP, owing to the high conversion efficiency, cost effective reactants and catalyst, and relatively lower energy use [20–22]. In order for this process to reduce the environmental impact, improvements on the efficiency of the washing and effluent treatment steps are warranted. Recently, there are considerable amount of research on dry washing which selectively absorbs impurities from the product [23–25]. More recent investigations are focusing on finding suitable adsorbents [26–30].

Concerns over the downstream processing of the homogeneous transesterification processes have motivated intense research on the heterogeneous transesterification method [31–35]. In general, the heterogeneous biodiesel production processes have less number of unit operations, with simpler separation and purification steps of products as there is no neutralization process required. The effectiveness of the heterogeneous catalyst conversion depends on the effectiveness of the solid catalyst used. There are three types of solid catalysts: acid, base and enzyme. Solid base catalysts such as alkaline-earth metal hydroxide, oxides, and alkoxides such as $Ca(OH)_2$, CaO, and $Ca(CH_3O)_2$ function as effective catalysts for the transesterification of triglycerides [35]. The surface area and basicity determines the reactivity of the alkaline-earth metals. So far, the catalytic activity of alkali hydroxide catalyst is found to be higher than alkaline-earth metal. In addition, alkali- and alkaline-earth metal cations are prone to dissolve in solvents, including biodiesel, and the base catalyst is readily poisoned by water [35].

In general, solid base catalysts are more reactive than solid acid catalysts requiring relatively shorter reaction time and lower reaction temperature [35]. However, solid acid catalysts have several advantages over solid base catalysts such as the reaction is less affected by the presence of water and free fatty acids [36]. The main advantage of solid acid catalysts is its ability to carry out the esterification of free fatty acids and transesterification of triglycerides simultaneously [33,34,37]. Hence, a solid acid catalyst is ideal for low-quality feedstock (generally high free fatty acids and water content), thereby lowering the overall production costs.

Among the solid acid catalysts, tungstated zirconia–alumina (WZA), sulfated zirconia–alumina (SZA), sulfated tin oxide (STO), amberlyst-15 (sulfonated polystyrene-based resin), nafion NR50 (perfluorinated alkane sulfonic acid resin), and metal compounds such as TiO_2/ZrO_2, Al_2O_3/ZrO_2, ferric sulfate and ZnO are most widely studied [33,35]. Furuta et al. [38] evaluated WZA, SZA, STO, TiO_2/ZrO_2, and Al_2O_3/ZrO_2 in the transesterification of soybean oil with methanol at 200–300 °C and esterification of n-octanoic acid with methanol at 175–200 °C, using a packed bed reactor. Tungstated zirconia–alumina (WZA) shows potential as it gives high conversion in esterification and transesterification reactions and is stable at relatively higher temperature (250 °C).

Recent discovery of the sugar catalyst (also known as sulfonated carbon catalyst) by Toda et al. [39] also contributes to the development of solid acid catalysis for biodiesel production. Sugar catalyst made from sulfonating the pyrolized sugar, is inexpensive and prepared from environmentally benign, renewable catalyst support. It is shown to be very stable with comparable acidity to sulfuric acid, and higher catalytic reactivity than all typical solid acid catalysts [39–41]. Moreover, it is reactive on esterification and transesterification reactions at relatively low temperature (i.e., 80 °C). However, more trials and experiments are needed to validate the application of this catalyst. Mo et al. [42] have shown that the sugar catalyst is not as stable as claimed by Toda et al. [39]. Another more recently reported solid acid catalyst reactive at relatively lower temperature is $H_4PNbW_{11}O_{40}/WO_3–Nb_2O_5$, a novel heteropolyacid derived catalyst [35].

Enzyme-catalyzed transesterification is another way to achieve biodiesel production. Lipase has shown to have high catalytic reactivity to produce high quality biodiesel [43,44]. Enzyme production is a renewable process, but currently more costly than

Table 1
Typical vegetable oil properties and methyl ester yields through alkaline- and acid-catalyzed, and supercritical methanol conversion.

Raw material	FFA content (wt%)	Water content (wt%)	Yields of methyl esters (wt%)		
			Alkaline-catalyzed	Acid-catalyzed	Supercritical methanol
Rapeseed oil	2.0	0.02	97.0	98.4	98.5
Palm oil	5.3	2.1	94.4	97.8	98.9
Frying oil	5.6	0.2	94.1	97.8	96.9
Waste palm oil	>20.0	>61.0	–	–	95.8

Source: Ref. [148] Kusdiana and Saka.

the conventional solid catalysts, owing to the higher cost of enzyme production requiring more complicated and high technology instrumentations [45]. One of the challenges in using enzyme as a biocatalyst is its reusability as enzymes can leach out. Thus, a lipase immobilized on solid material such as porous kaolinite functions as a reusable heterogeneous catalyst [35]. Another problem with the use of lipase is its deactivation by glycerol which blocks the active sites of lipase, requiring efficient product separation to maintain the reactivity of lipase. The use of methanol in the triglycerides transesterification catalyzed by a lipase is limited to only a maximum methanol-to-oil molar ratio of 1:1, above which it seriously inactivates the enzyme [46]. Recent findings show that an alternative acyl acceptor such as methyl acetate to replace methanol can attain up to 92% methyl ester yield. In addition, the by-product of triacetylglycerol has more expansive market than glycerol, and does not deactivate the lipase [46,47].

Supercritical methanol is another way of making biodiesel via transesterification reaction at high temperature and pressure (e.g., 350 °C, 43 MPa) without any catalyst [48–52]. The reaction requires a very high methanol-to-oil molar ratio (42:1), but is completed in less than 4 min [53–55]. As shown in Table 1, the supercritical methanol process can tolerate higher FFA and water contents with less reaction time compared to the alkaline- and acid-catalyzed conversion processes [56–59]. However, higher production cost due to the extreme reaction condition, and the negative environmental impact due to the use of large amount of methanol albeit recycled, hinder the commercialization of supercritical methanol process [45].

An economic comparison between different conversion methods is reported using HYSYS simulator [60,61]. The results show that the heterogeneous acid catalyst process has the lowest total capital investment and manufacturing cost, and the only positive after rate-of-return for a plant capacity of 8000 metric tones/year biodiesel production [61]. Furthermore, there are several excellent reviews on heterogeneous catalysis for biodiesel production available in the literature [35,62,63].

2.2. Feedstocks

While various biodiesel feedstock is renewable, its competition with food source is a major concern. The increase in staple food prices is connected with the use of edible oil for biodiesel production [64]. Interesting perspective lies in the argument that the amount of vegetable oil produced in the world can meet the demand for consumption and for consumer products [65]. However, the issue goes beyond the supply—encompassing the complex balance in the ecosystem. For instance, the mass plantation of monoculture plants could benefit the economy of rural population while negatively affecting the water resources and the biodiversity [64].

Table 2
Oil yield for major non-edible oil resources.

Oil source	Oil yield (kg oil/ha)	Oil yield (wt%)
Jatropha	1590	Seed (35–40); Kernel (50–60)
Rubber seed	80–120	40–50
Castor	1188	53
Pongamia pinnata	225–2250	30–40
Sea mango	N/A	54

Source: Ref. [19] Gui et al.

2.2.1. Non-edible oil

One of the ways to reduce the dependency on edible oil to make biodiesel is to use non-edible oils, such as jatropha, castor, *Pongamia pinnata*, rubber seed, and sea mango [19]. Table 2 shows oil yield for major non-edible oil sources, including those that have been commercialized to produce biodiesel. Conversion of these types of oil into biodiesel is comparable in the process and quality to other edible oils [15].

Jatropha curcas in particular has an extra advantage over other oil sources because it is a drought-resistant plant capable of surviving in abandoned and fallowed agricultural land [66,67]. This will give extra income for the local farmers without sacrificing the fertile land that is used for other crops. However, more research is needed to fully commercialize jatropha oil including such information as basic agronomic characteristics of *J. curcas* [64].

2.2.2. Algae-based biodiesel

There is a growing interest in algae-based biodiesel for its higher yield non-edible oil production, and does not compete for land with food production [68–70]. Table 3 shows the comparison of the biodiesel production from algae and oil plants. Algae-based biodiesel has a superior yield per hectare over conventional oil

Table 3
Comparison of biodiesel production from algae and oil plants.

	Biodiesel produced from algae	Biodiesel produced from plants
Technology	Cell bioengineering, automatically produced in pilot plant	Agriculture in farm
Production period	5–7 days for a batch cultivation	Several months or years
Oil content	More than 40–50% in whole cells	Less than 20% in seeds or fruits
Land occupied	0.010–0.013 hectare for producing 1×10^3 L oil[a]	2.24 ha for producing 1×10^3 L oil[b]
Cost performance	$2.4 per liter microalgal oil	$0.6–0.8 per liter plant oil
Development potential	Unlimited (work just beginning)	Limited (many works have been done)

Source: Ref. [69] Li et al.
[a] Based on projected area of bioreactor in pilot plant.
[b] Based on soybean cultivation in farmland.

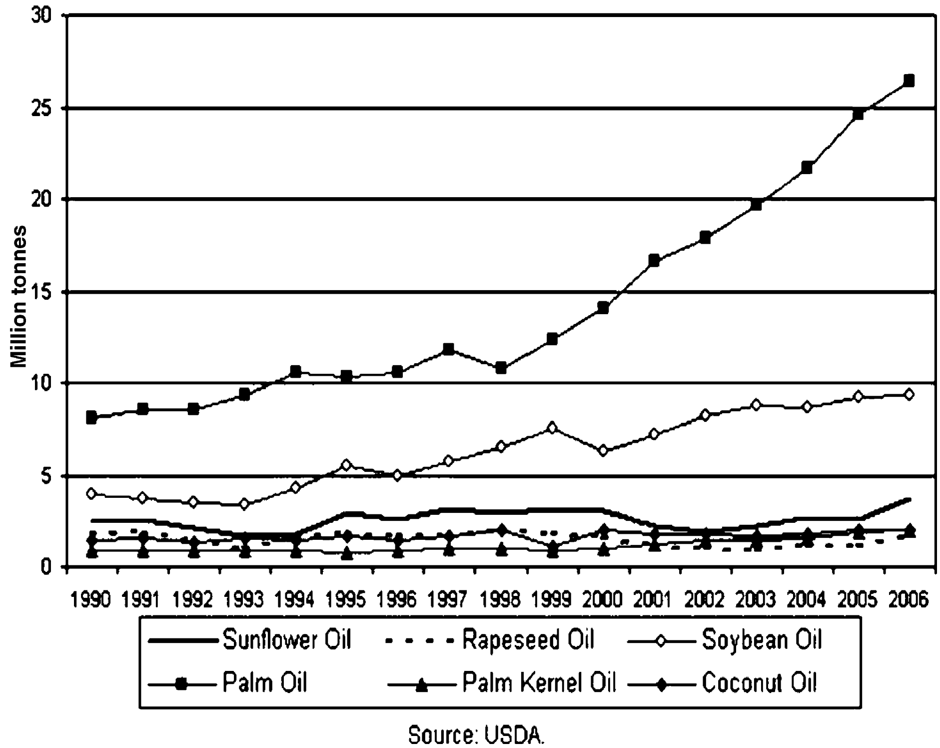

Fig. 1. Global vegetable oil production (source: Ref. [149] Carter et al. Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.).

crops. This is because algae can be grown in farm or bioreactor. The main obstacle for the commercialization of algae-based biodiesel is its high production cost from requiring high-oil-yielding algae strains and effective large-scale bioreactors [71]. Recent studies indicate that algae for biodiesel production can grow on flue gas, giving opportunities in consuming greenhouse gas as feedstock [69,72]. Further details are found elsewhere [73].

2.2.3. Waste oils, grease, and animal fats

Waste vegetable oils, greases, and animal fats have already been used as feedstock for biodiesel production. The use of these types of feedstock eliminates the need to dispose them, and more importantly contribute to the supply of biodiesel. However, the major challenges, especially for waste stream feedstock, such as waste cooking oil and grease, are the collection infrastructure and logistics. For example, the collection system for the waste cooking oil could be a hurdle as the sources are generally scattered and without any quality control. The city of Kyoto has taken this challenge and reported on producing enough biodiesel to fuel their city buses from waste vegetable oils collected from general households, restaurants and cafeterias [74,75]. In certain remote or seasonal communities, it may feasible for this type of model to work. However, further public awareness, education and acceptance become key importance for a successful implementation.

Meanwhile, animal fats are more readily available as the slaughter industry is generally well managed for product control and handling procedure. However, there is a biosafety issue related to animal fats that could come from the contaminated animals. The future research needs for ensuring biosafety of biodiesel produced from animal waste from cradle to grave has been highlighted [76].

2.2.4. Edible oil from sustainable plantation

The use of edible vegetable oil as a feedstock to biodiesel production warrants a discussion. Despite the fact that neat edible oil competes with food supply, it is the feedstock that allows the simplest conversion method. Furthermore, for many, the edible oil crop plantation has already been well established, with some crops producing high quality oil that gives highest conversion through the transesterification reaction. The central issue is the proper management on the oil supply so that oil for food consumption and for consumer products are guaranteed, with the remaining oil be converted into biodiesel. A sustainable plantation is comprehensive practices that maintain the benefits to the environment (planet), people, and profitability [77]. To illustrate the practise of sustainable plantation, a case study is presented from the palm oil plantation in Malaysia.

2.2.4.1. Sustainable plantation: a case study of palm oil plantation in Malaysia. Palm oil is currently the largest supply of edible oil in the world with Malaysia being the largest producer (Indonesia is second to Malaysia as the largest exporter of palm oil in the world) [78,79]. Palm oil has dominated the world's vegetable oil demand because of its versatile applications ranging from food to consumer products, and now as biodiesel. Fig. 1 shows the global vegetable oil production. The large supply of palm oil can be attributed to the superiority of palm oil in terms of oil yield, shown in Table 4, requiring smaller area of land to produce oil. Furthermore, palm oil has the highest fossil energy balance, i.e., energy produced over energy consumed as defined in Table 5, and the lowest production cost relative to other energy crops (Fig. 2). The success of palm oil industry in Malaysia is achieved based on the highly desirable properties of the palm oil trees, careful management by Malaysian

Table 4
Oil production and yield of major oil crop in 2006.

Oil crop	Average oil yield (tones/ha/year)	Planted area (million ha)
Soybean	0.40	94.15
Sunflower	0.46	23.91
Rapeseed	0.68	27.22
Oil PALM (mesocarp)	3.62	10.55

Source: Ref. [79] Sumathi et al.

Table 5
Estimated ranges of fossil energy balance of biodiesel and diesel.

Fuel	Feedstock	Fossil energy balance (ratio)[a]
Biodiesel	Soyabean	14–3.4
	Rapeseed	1.2–3.6
	Waste vegetable oil	4.8–5.8
	Palm oil	8.6–9.6
Diesel	Crude oil	0.8–0.9

Source: Ref. [64] FAO.
[a] The fossil energy balance = [energy contained in the fuel]/[fossil energy used in its production].

Palm Oil Board (MPOB), and more importantly the sustainable practice in palm oil farming [77,80,81].

Oil palm cultivation in Malaysia has long advocated sustainable practices. It has struck a balance between economic needs and preservation of the environment. Laws including the Protection of Wildlife Act 1972 were already in place when the industry saw a surge in planted area from the 1980s [77]. The oil palms were originally forest species which have been domesticated to maximize the yield of their respective products. It is estimated that palm oil crop emits eight to ten times more oxygen and absorbs up to ten times more CO_2 per hectare per year compared to annual crops grown in temperate countries [77].

However, there are many issues concerning the oil palm cultivation in Malaysia such as deforestation, Orangutan extinction, and peatland destruction being addressed in several publications [77,80–84]. In summary, Malaysia has been practicing the roundtable on sustainable palm oil (RSPO) to involve NGOs in effort to be transparent and maintain best management practices. The world's acceptance of the plantation in Malaysia is well reflected from the increase demand for oil palm year by year.

In terms of the properties of biodiesel derived from palm oil, generally it meets the EN14214 and D6751 standards with exception to the cold flow properties [85–88]. Palm oil biodiesel is typically associated with high cloud point and pour point limiting its usage in warmer climates [89]. However, there are several treatments such as winterization, additives and blending with other oils which could change the cold flow properties of palm oil biodiesel [90–95].

2.2.5. Genetically engineered plants

Genetically engineered plants can be used to enhance the plant's oil yield (e.g., increase protein and oil content in corn), incorporate noble attributes (i.e., plants resistant to drought and diseases), and suppress undesirable properties (e.g., suppressing the methyl bromide-producing gene in Canola oil) [96–99]. This field is expected to grow for achieving sustainable biodiesel or biofuel production, especially to create new bioenergy crops that are not associated with food crops. Examples of such crops are poplar, switchgrass, miscanthus and big bluestem which are considered to have energetic, economic and environmental advantages over food crops [100]. However, precaution on biosafety must always be considered for genetically engineered crops [98].

3. Cleaner emissions

One of the attractions to biodiesel is its biodegradability and being more environmentally benign than the fossil fuels, resulting in less environmental impact upon accidental release to the environment. However, as a vehicular fuel, there are numerous studies on the safety, health and environmental effects of biodiesel emissions [101–105].

Recently, five methyl ester biodiesel samples (palm oil, soybean, rapeseed, cottonseed, and waste cooking oil methyl esters) were run on a Cummins ISBe6 direct injection engine, comparable with the Euro III diesel engine standards, and tested for emissions [106]. Results are comparable to previous studies [107,108] showing the reductions in particulate matter ranging from 53% to 69%; dry soot ranging from 79% to 83%; hydrocarbons ranging from 45% to 67%; and carbon monoxide ranging from 4% to 16% compared to petroleum diesel. However, nitric oxides (NOx) show slight increase ranging from 10% to 23%. Reasons for the variations of the emission performance of each methyl ester are associated with the oxygen content and viscosity of the methyl esters, and these properties are resulted from the properties of the feedstock. In order for the biodiesel fuel to remain acceptable by the public, more research is warranted to improve the emission qualities.

There are many efforts to further improve the quality of emissions from biodiesel-containing fuels. Blending biodiesel,

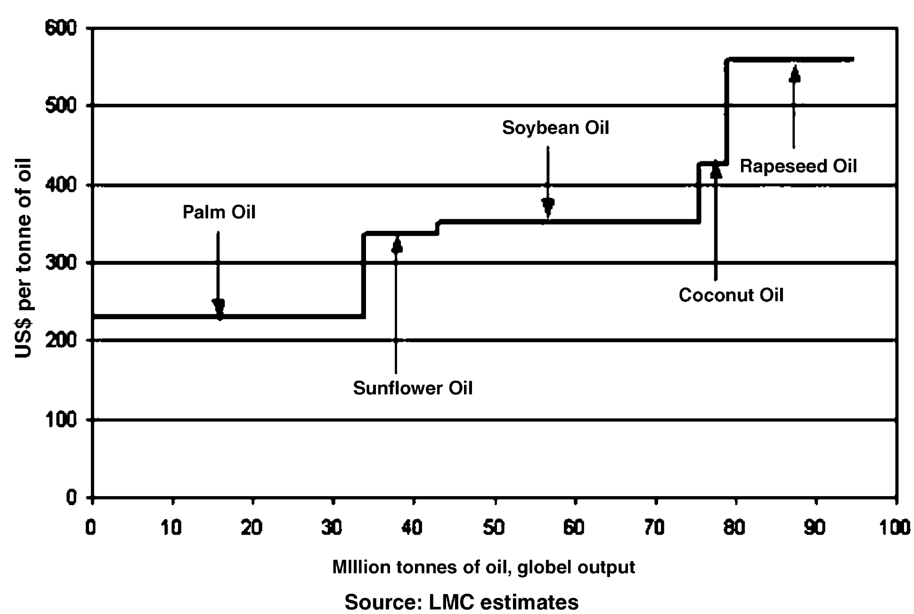

Fig. 2. Average cost and quantity of vegetable oil production, 2004/05 (source: Ref. [149] Carter et al. Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.).

ethanol, and diesel known as diesterol [109] has been investigated [110,111]. Ethanol works as fuel oxygenates to increase the oxygen content, which is desirable to increase the octane number of the fuels; however, addition of ethanol reduces the heat content (gross heat content of ethanol, diesel (No. 2), and methyl soyate are 27.0, 42.5, and 38.0 MJ/kg, respectively) [110]. Addition of biodiesel compensates the heating value loss due to the addition of ethanol, and increases the fuel stability and the cold flow properties [109,110]. In general, the torque of engine almost reduces linearly with the addition of ethanol to diesel fuel due to the low heating value of the ethanol. Biodiesel–ethanol–diesel blends reduce smoke and PM significantly, while NOx remain the same or slightly increased. Nevertheless, the reductions of HC and CO emissions vary with the operating conditions.

Lin et al. [112] reported the use of emulsified biosolution–biodiesel–diesel blends to increase energy saving and to reduce pollutions from diesel engines. The biosolution is prepared from natural organic enzyme-7F (96.5 wt%) and water (3.5 wt%), a blend that is stabilized with surfactant, and results in reduction of PM and polycyclic aromatic hydrocarbons (PAHs) emissions from diesel engines compared to diesel and biodiesel–diesel blends. Further investigations are required, especially on the economics of using enzymes.

Recent development in the reduction of hazardous emissions from diesel engines is the use of fuel oxygenates derived from biodiesel glycerol. Glycerol has long been known to produce mono-glyceryl ethers, di-glyceryl ethers, and tri-glyceryl ether via etherification reaction using isobutene or *tert*-butanol in the presence of solid acid catalyst such as amberlyst-15 [113–117]. Blending di- and tri-glyceryl ethers with biodiesel improve the cloud point and pour point of biodiesel [118]. Moreover, they can replace the banned methyl *tert*-butyl ether (MTBE) as fuel oxygenates. MTBE was found to be recalcitrant and harmful to human [119–122], and has been fully banned as fuel oxygenates in the US since 2006 due to contamination in the surface and ground waters [123]. Recently, Jaecker-Voirol et al. [124] reported an emission performance test for various biodiesel formulations including di- and tri-glyceryl ethers–biodiesel blends releasing less regulated and toxic air pollutants compared with biodiesel alone. However, the use of isobutene to produce di- and tri-glyceryl ethers from glycerol needs further research as isobutene is expensive, currently made from non-renewable source and requires high pressure for the glycerol etherification reaction.

4. Diversification of products derived from biodiesel glycerol

With the increase in biodiesel production world-wide, the market saturation of glycerol, a by-product of biodiesel production, is inevitable [125]. Besides the application to produce glyceryl ethers discussed previously, there are many other applications for use of crude glycerol as listed below, albeit not exhaustive:

(1) Catalytic conversion:
- Propylene glycol, propionic acid, acrylic acid, propanol, acrolein, propanediol, etc. [126–128]

(2) Biological conversion:
- Citric acid, sophorolipids, 1,3-propanediol, etc. [129–131]

(3) Fuel oxygenates:
- Acetal (2,2-dimethyl-1,3-dioxolan-4-yl) [132]

(4) Production of H_2 and syngas via steam gasification of glycerol [133,134]

(5) As carbon source for bioreactors treating Acid Mine Drainage [135]

(6) Agricultural usage:
- Broiler feed [136]; pig feed [137]

5. Policy and government incentives

The energy policy may include international treaties, legislation on commercial energy activities (trading, transport, storage, etc.), incentives for investment, guidelines for energy production, conversion, and use (efficiency and emission standards), taxation and other public techniques, energy-related research and development, energy economy, general international trade agreements and marketing energy diversity [138]. Globally, current energy policies reflect environmental issues including developing environmentally friendly technologies and increasing energy security and clean energy supplies [139–142]. In targeting reductions in GHGs, EU, Brazil, and Canada and others have mandated the use of biofuels in recent years [64,143]. For instance, the establishment of the Directive on the promotion of the use of biofuels for transport in EU (Directive 2003/30/EC) mandates an increasing share of biofuels from 2% of total fuel supply in 2005 to 5.75% of total supply in 2010 (based on energy content) [143]. The implementation of this directive triggers a huge demand for biodiesel, not to mention the target by other large countries like US and Canada. This type of policy is crucial for the establishment of the biodiesel industry.

Government incentives play an important role in sustaining the biodiesel industry especially during the economic crisis. There are many incentives that can be offered by a government to spur the industry and maintain its sustainability, such as crop plantation in abandoned and fallowed agricultural lands, and lands that currently sequester little carbon, and subsidies [144,145]. Incentives can be in the form of improved water management and conservation practices, and incentive to compensate the financial disadvantages if compared with the cultivation of good agricultural land. Implementation of carbon tax that rewards the use of renewable fuels including biodiesel and its blends (i.e., less or tax free fuel) over fossil diesel can catalyze the biodiesel industry [146].

One of the issues that can inhibit the development of the biodiesel industry is the various levels of commitment from the global community towards the reduction of GHG emissions, especially during the economic recession. As the GHG emissions is closely related to the industrial activity of a country, not all countries agree on the target to reduce their GHGs emissions. This can lead to fewer acceptances on the use of biodiesel. There must be a mechanism to encourage wider participation of the global community, such flexible GHGs emissions reduction target, to cultivate a ground which will further promote the use of renewable fuels [147].

6. Conclusions

Biodiesel is gradually gaining acceptance in the market as an environmentally friendly alternative diesel fuel. However, for biodiesel to establish and continue to mature in the market, various aspects must be examined and overcome. Some of the key issues such as improving efficiency of the production process, using low cost feedstock, developing cost effective catalyst, and managing agricultural land, have been reviewed. As with any new technology or products, biodiesel will require continuous improvement especially in producing cleaner emissions and having less impact on the environment. Further development on the use of the by-product will enhance the economic viability of the overall biodiesel production process. Finally, the incentives posed by the government resulting in promotion of the biodiesel production and usage will assist in establishing the biodiesel as a sustainable fuel.

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